

Stress and Fracture Permeability at Dixie Valley

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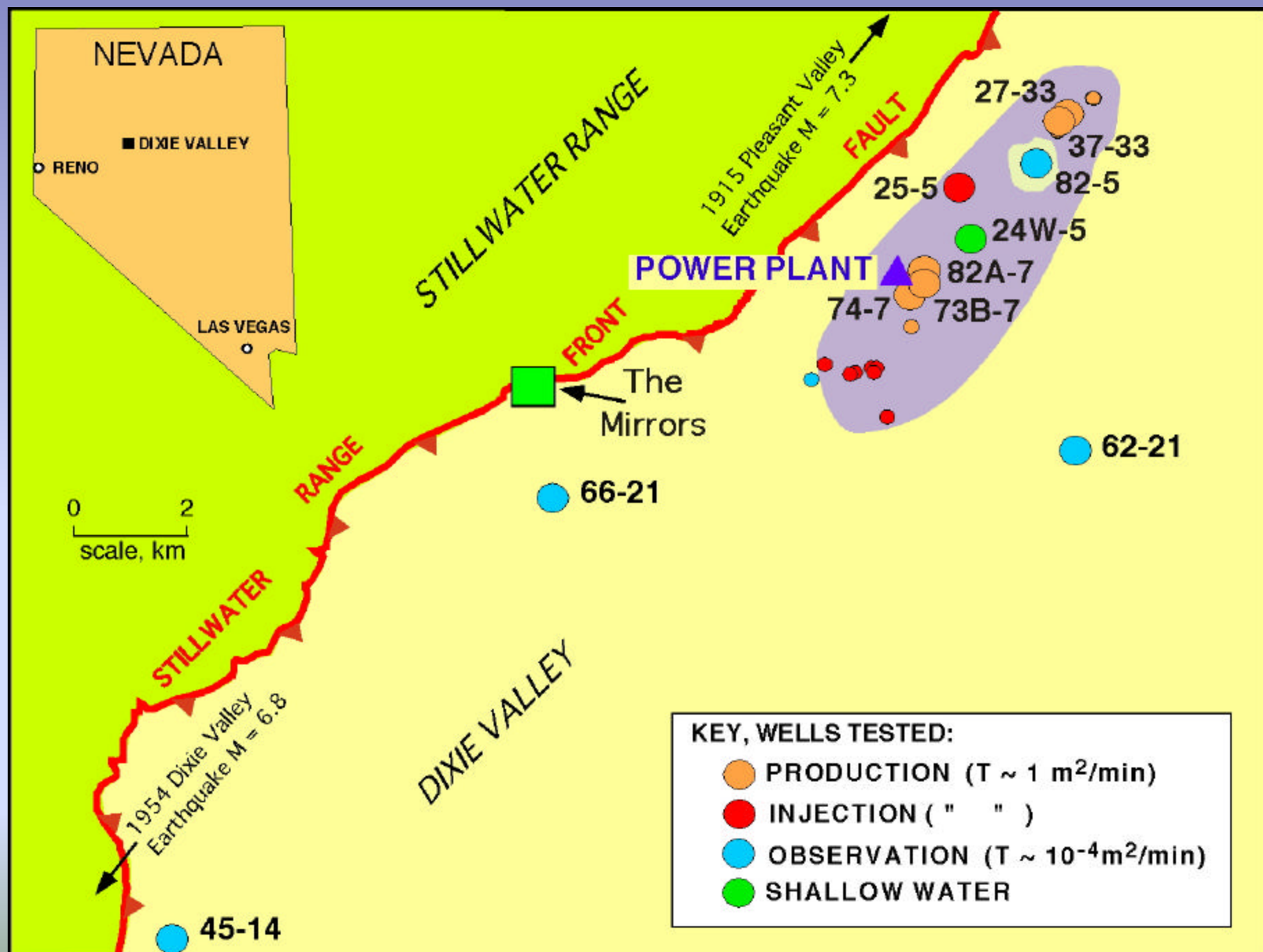
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***Workshop on Dixie Valley Geothermal Research
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GOAL: Determine role of tectonic stresses in controlling geothermal reservoir permeability at Dixie Valley

- Spatial variations
- Anisotropy

EXPERIMENTAL APPROACH

1. Study the distribution, orientation and hydraulic properties of fractures associated with the Stillwater fault:

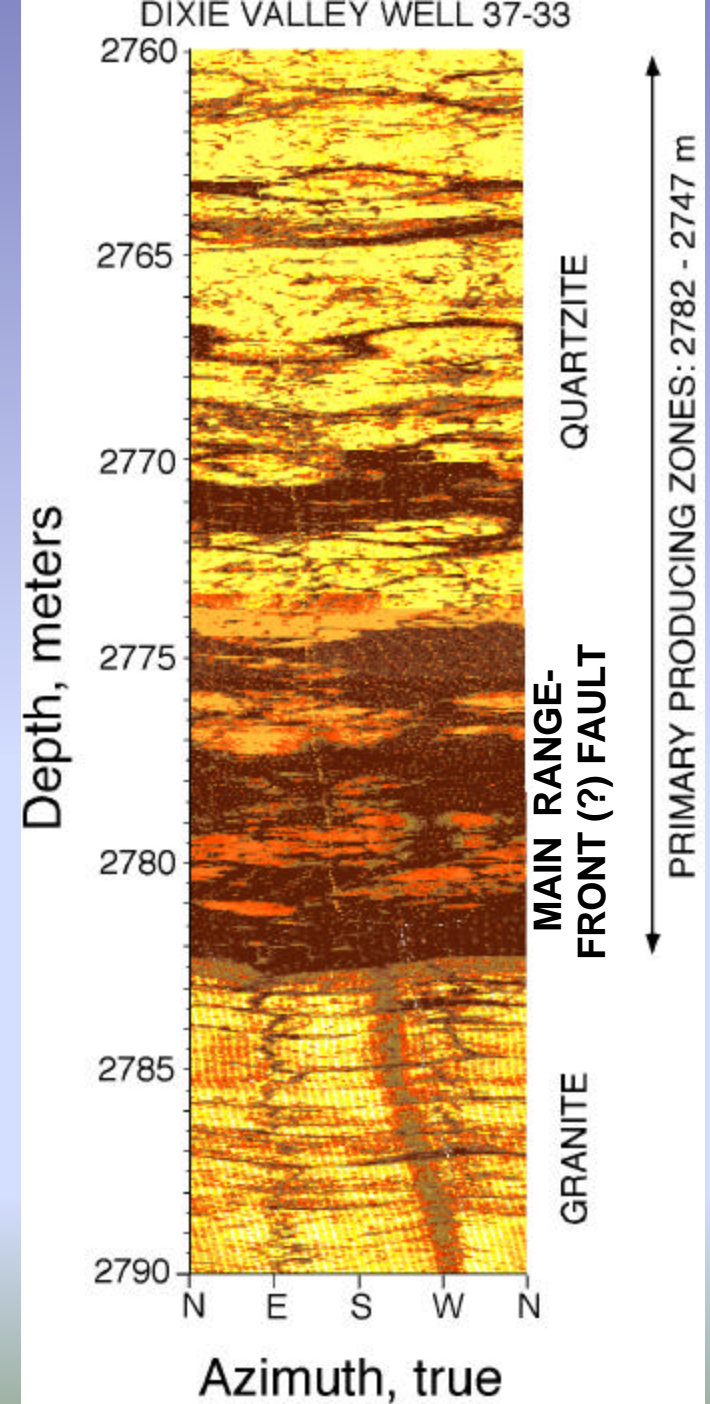
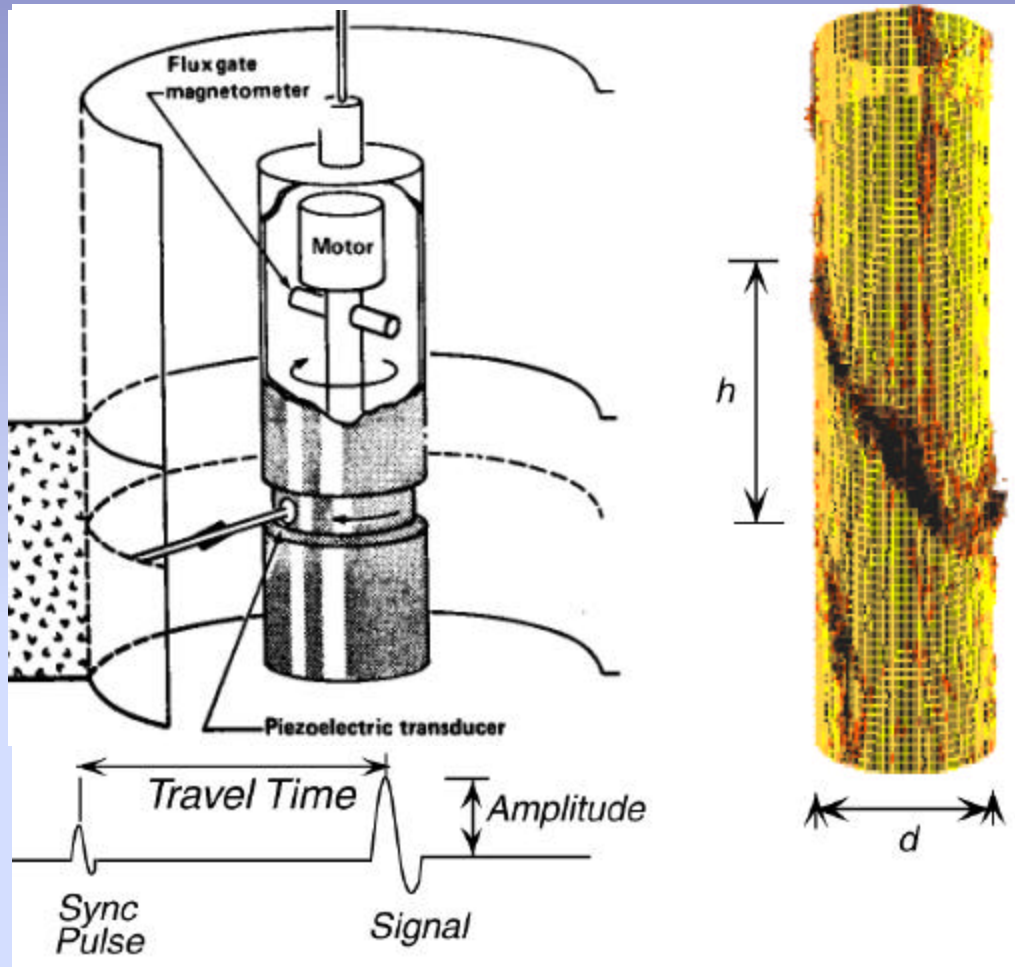
- borehole televiewer
- precision temperature logs
- spinner flowmeter

2. Determine if and in what manner the permeability of these fractures might be controlled by the local stress field:

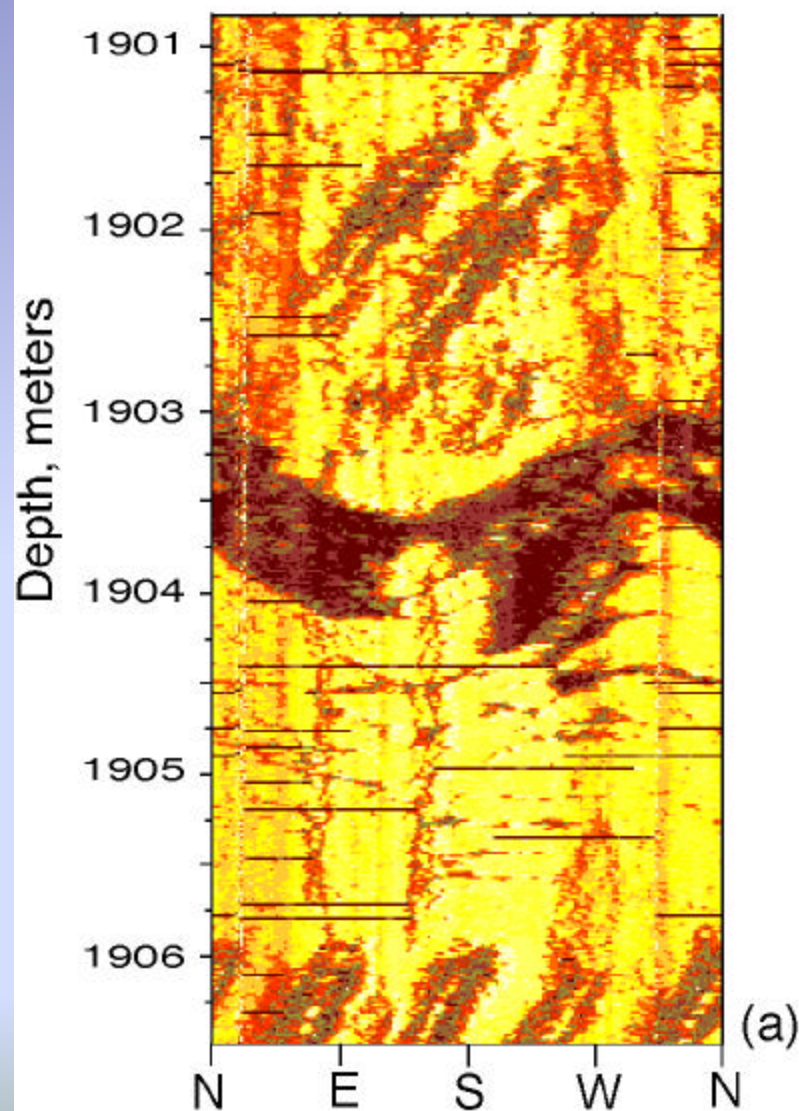
- hydraulic fracturing tests
- cooling fractures & breakouts



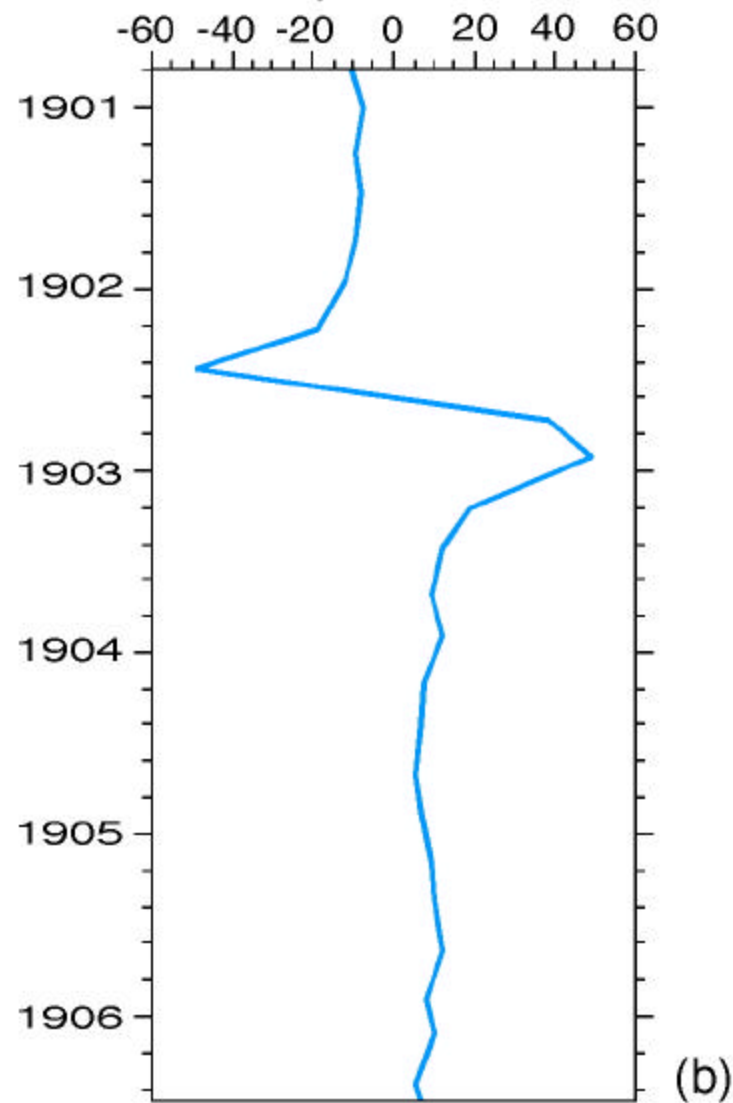
Borehole Televiewer Schematic

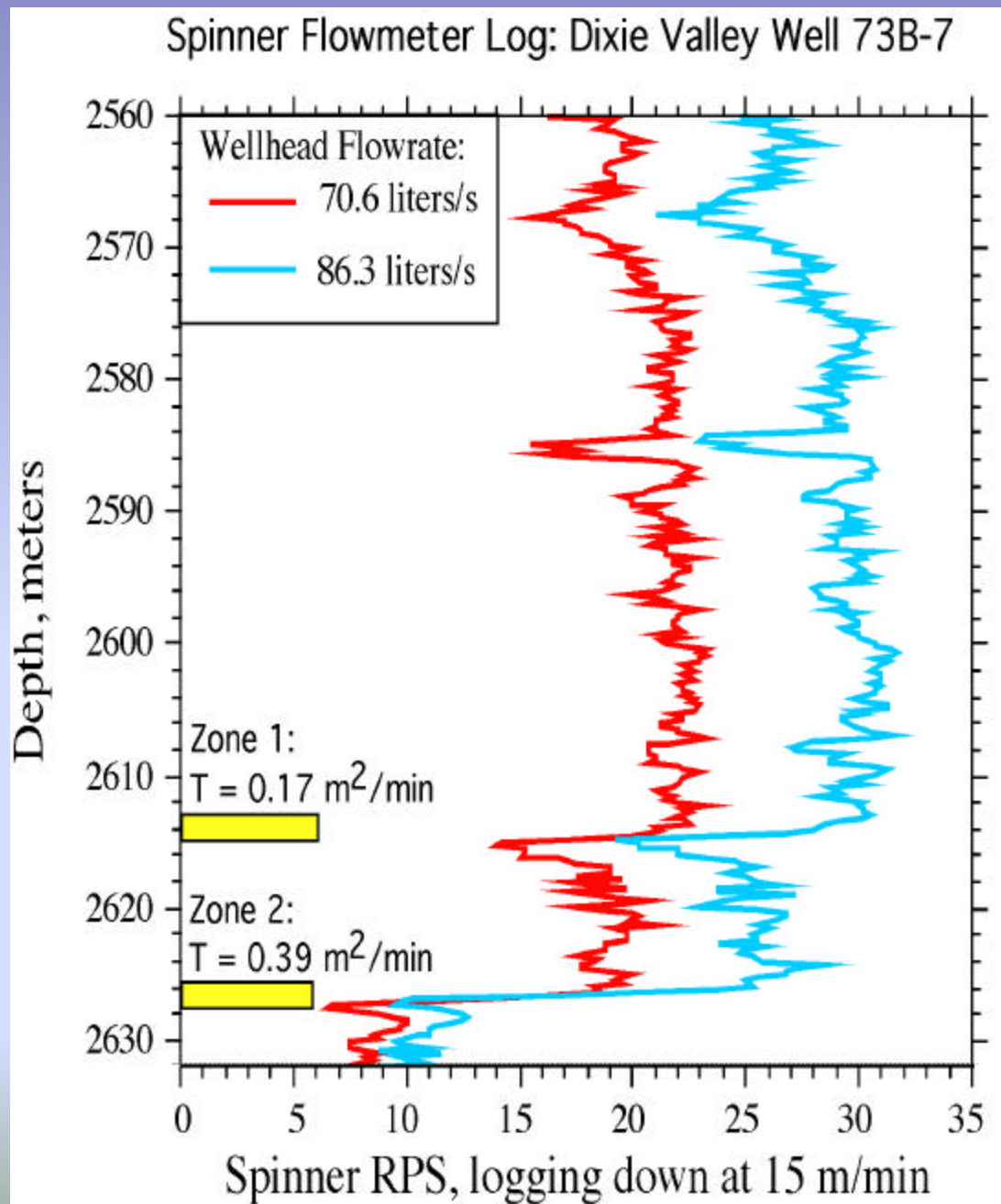
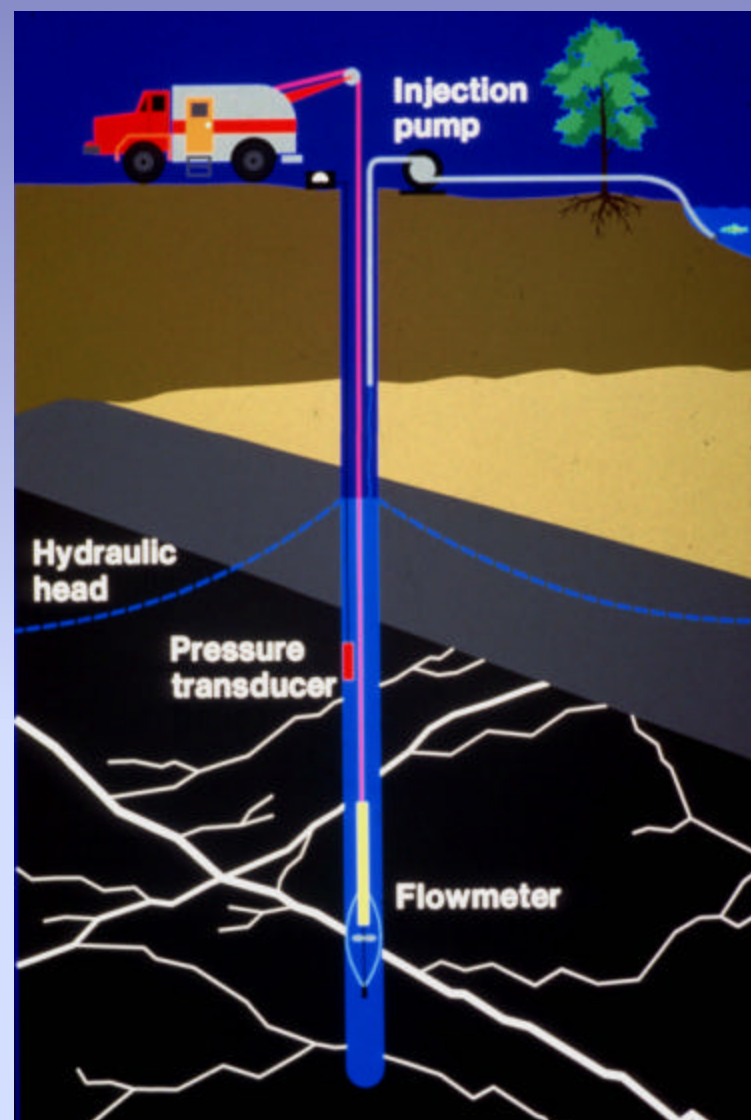


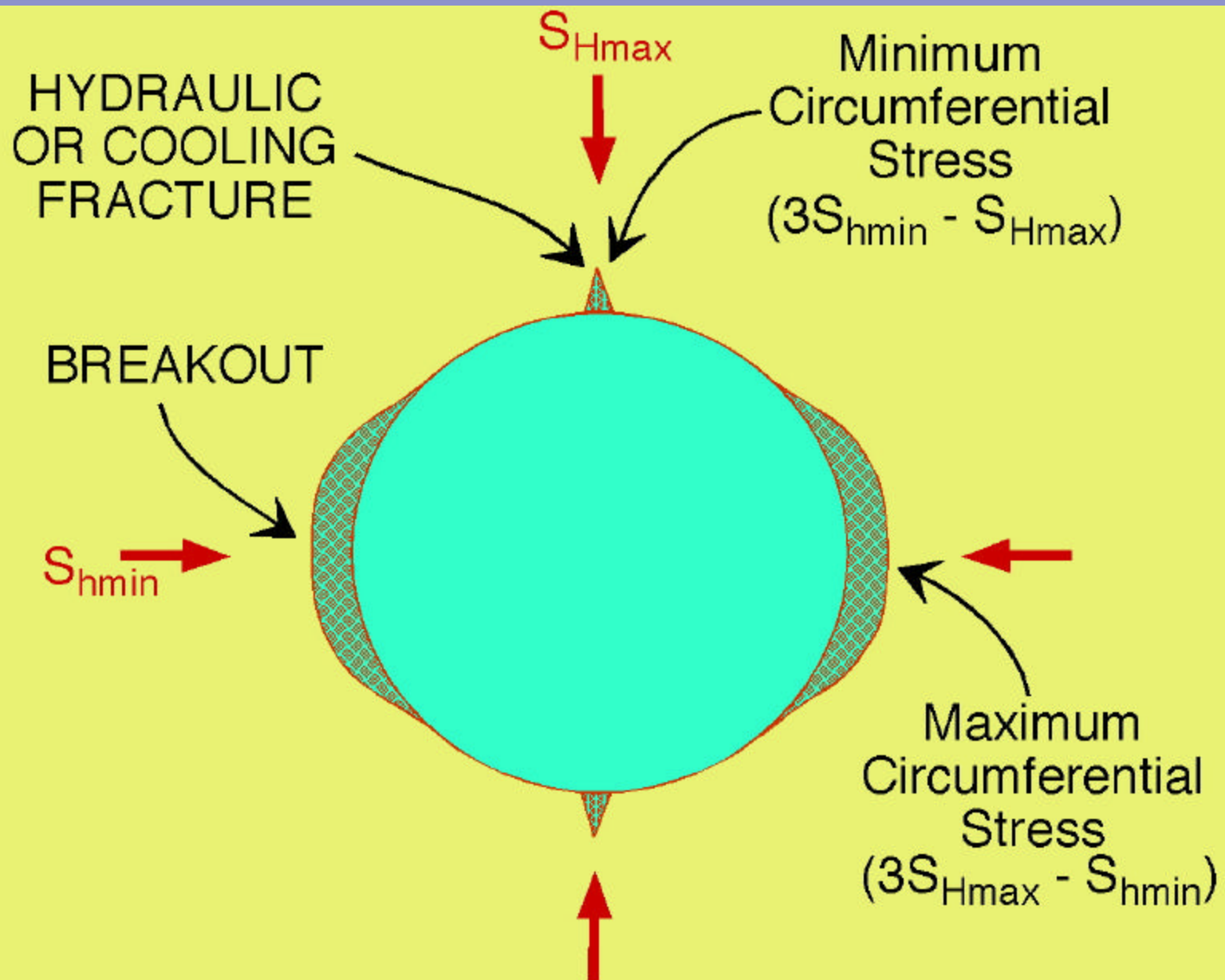
Borehole Televiewer Image



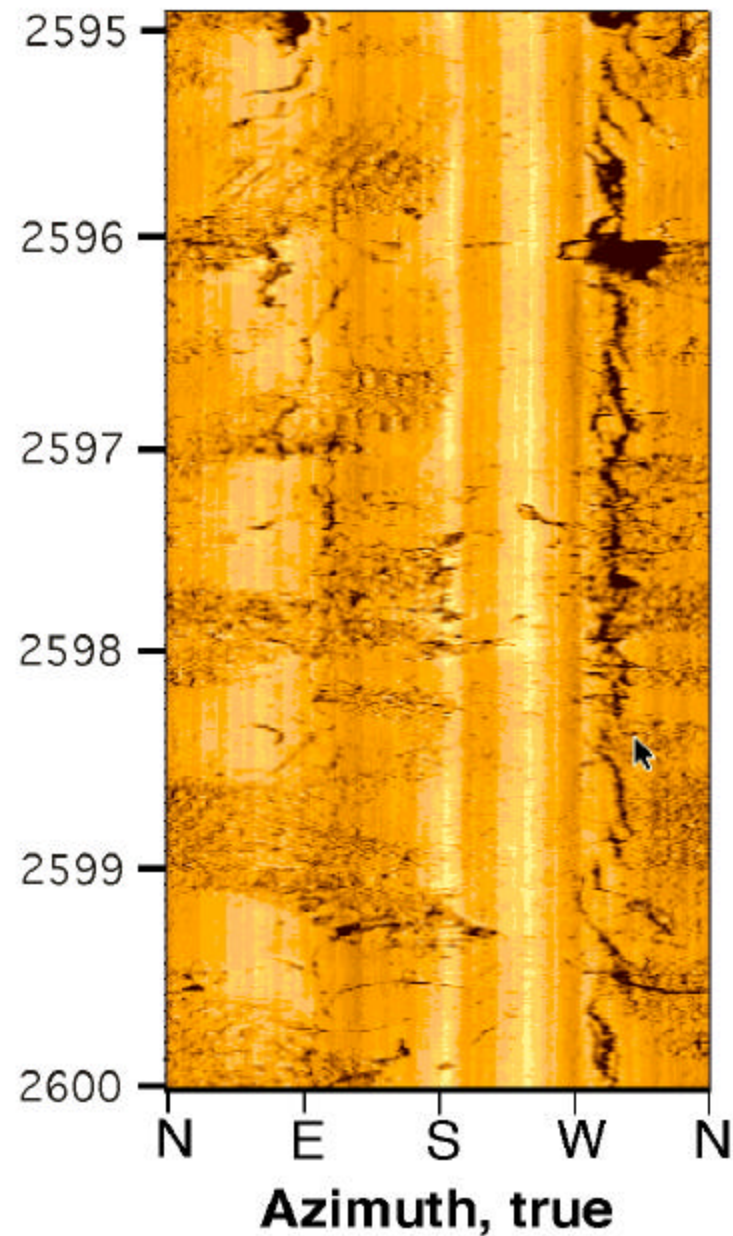
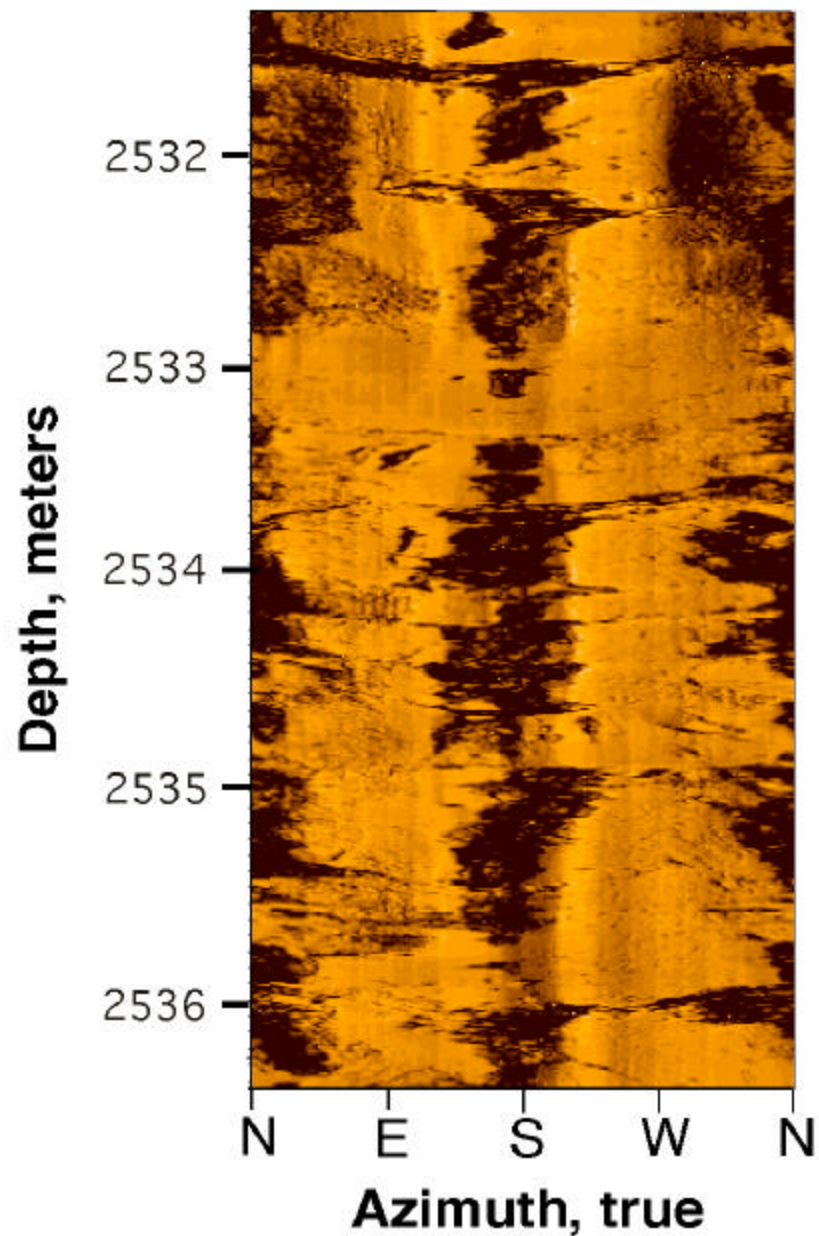
Relative Temp. Gradient, $^{\circ}\text{C}/\text{km}$





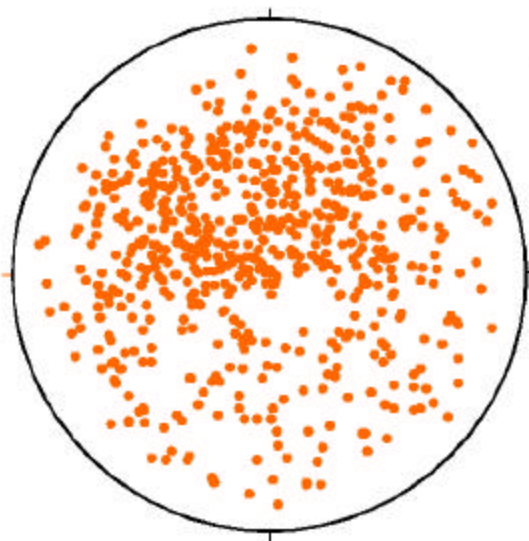


DIXIE VALLEY WELL 82-5

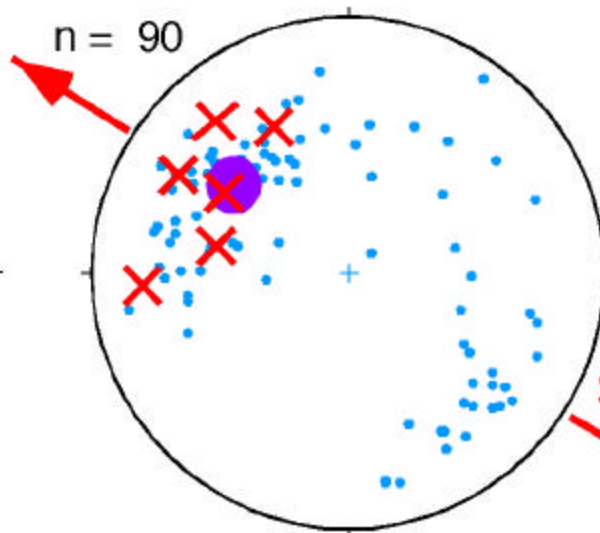


Lower Hemisphere Stereographic Projections

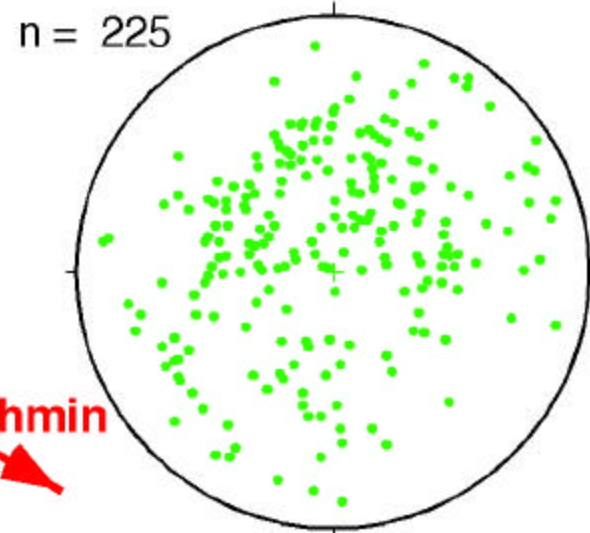
Poles to All Fracture Planes



Permeable Fractures



Impermeable Fractures

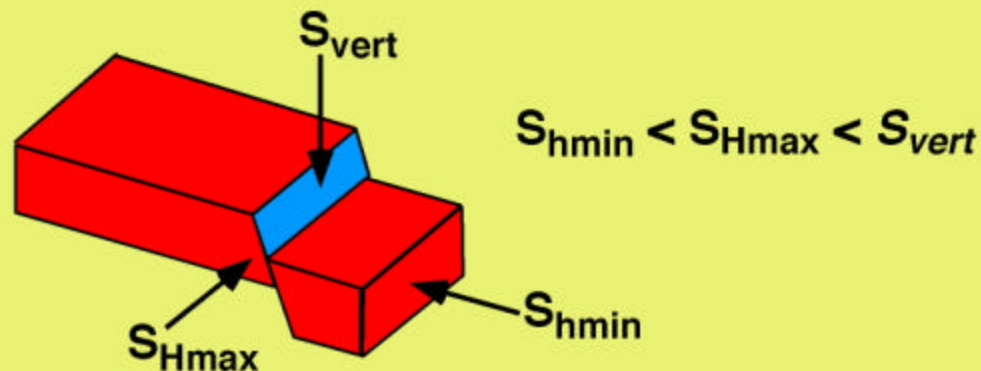


- ✗ Highly Productive Fractures
- Stillwater Range-Front Fault

Well 73B-7

Depth: 1850-2640 m

NORMAL FAULTING



- PRODUCTION WELL
- INJECTION WELL
- OBSERVATION WELL

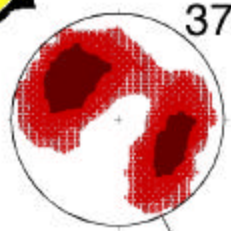
STILLWATER RANGE

STILLWATER FAULT

POWER PLANT

DIXIE VALLEY

0 1 2 km



37-33

27-33
28-33

82-5

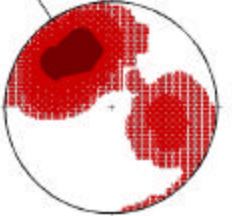
25-5

S_{hmin}

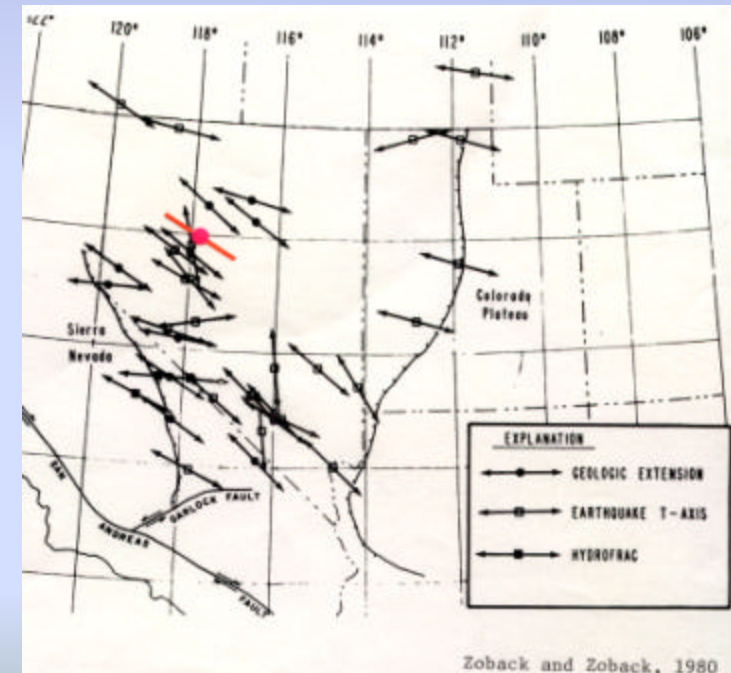
73B-7

S_{hmin}

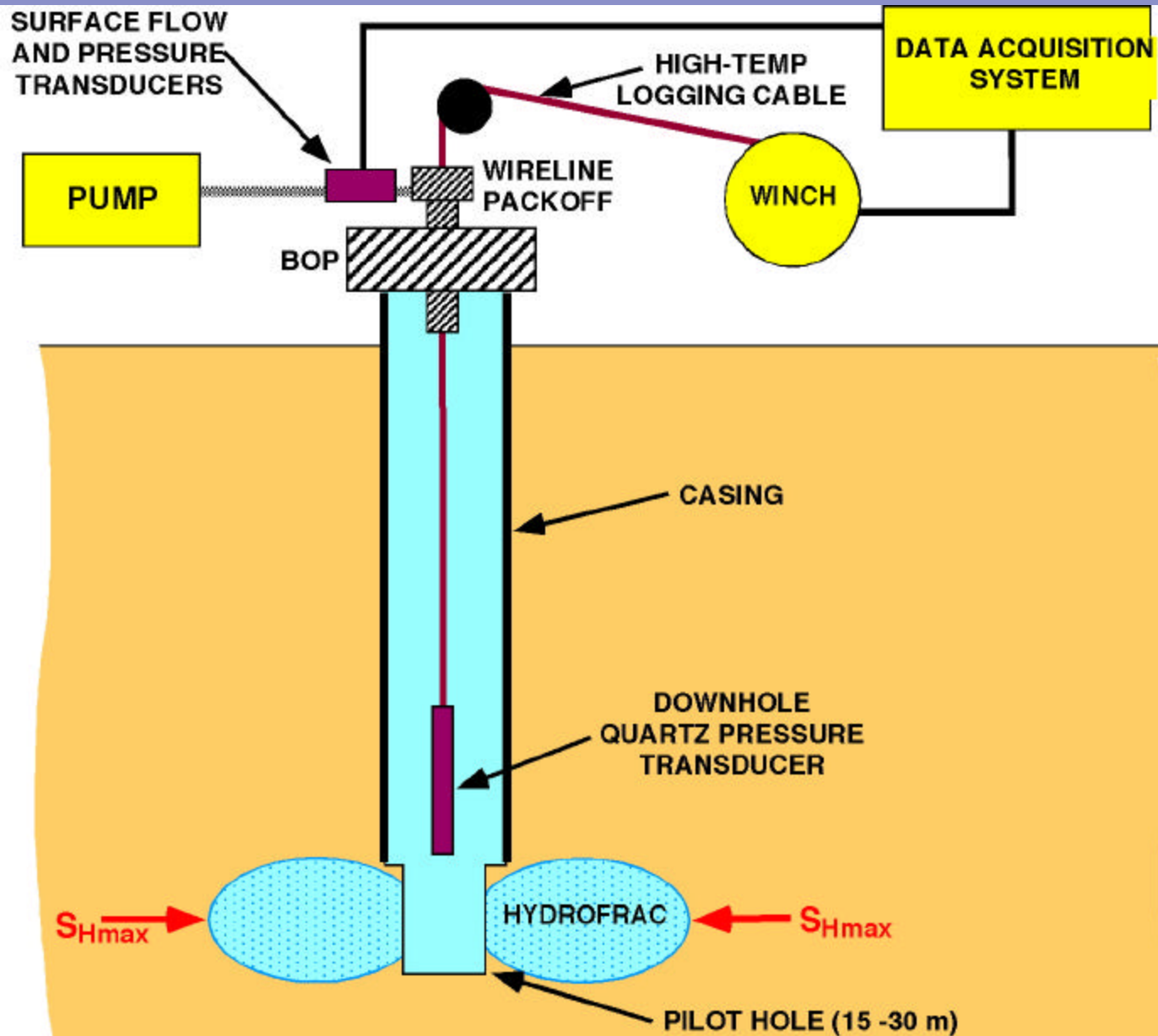
74-7

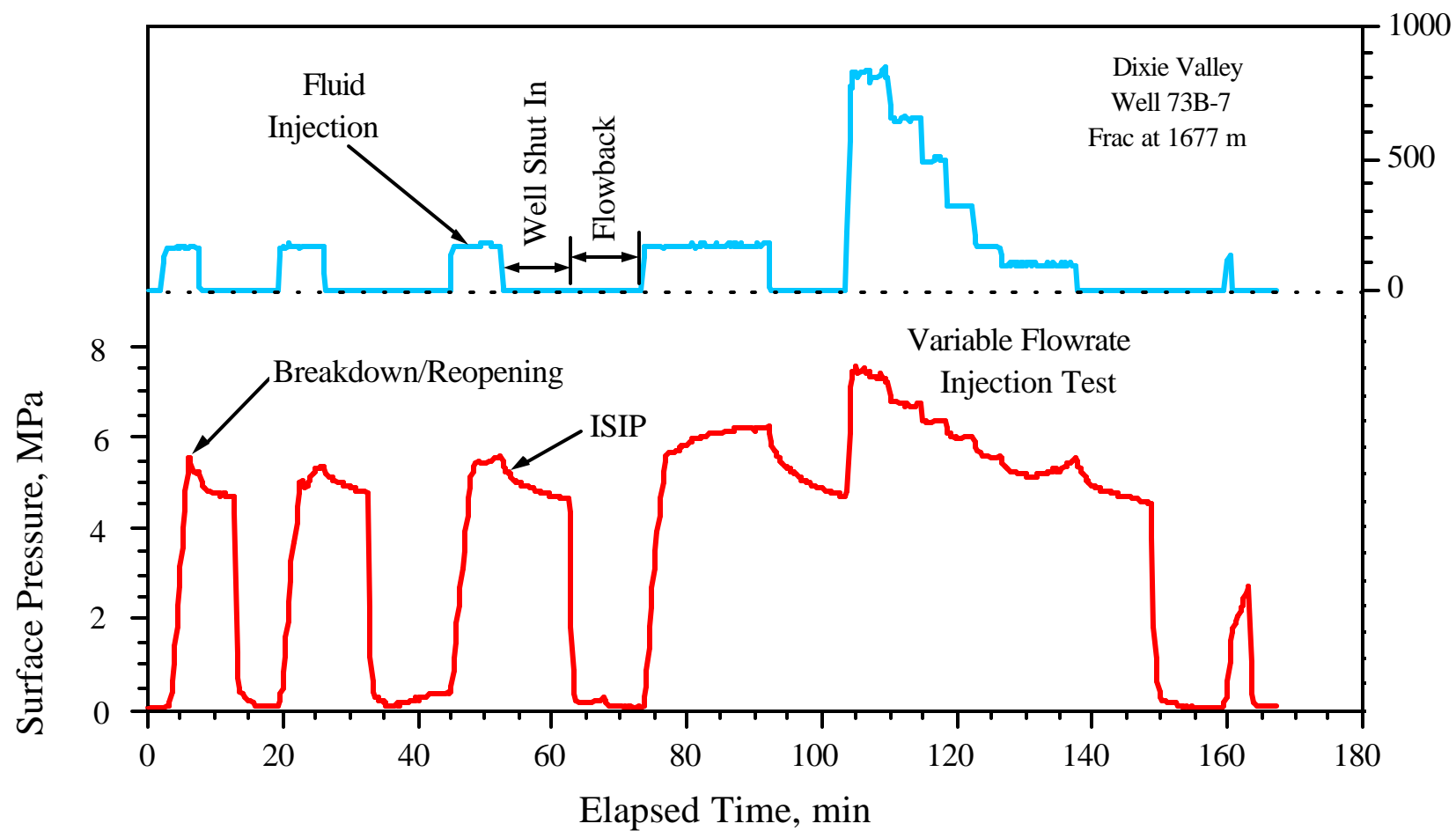


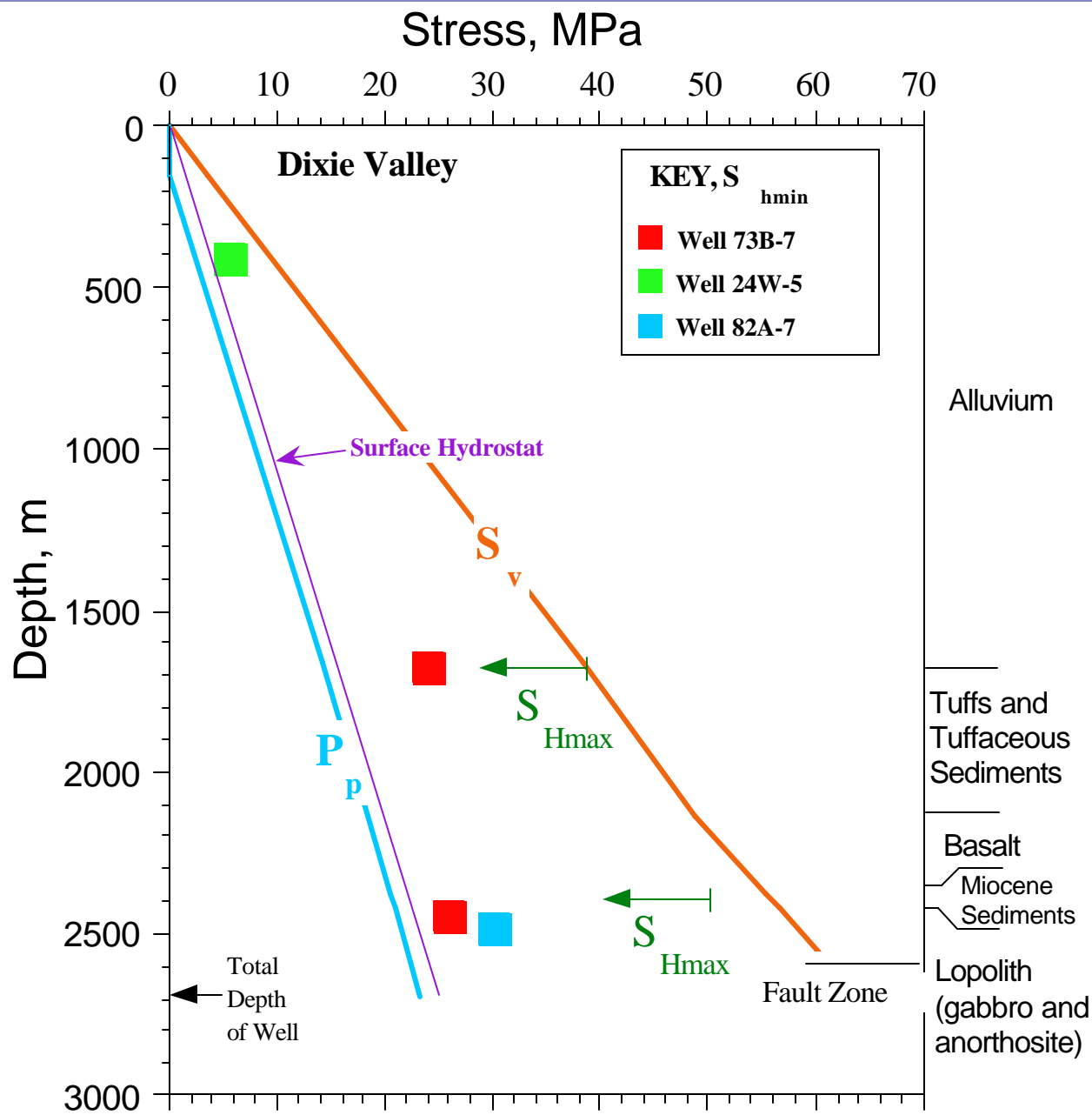
Dixie Valley Geothermal Field: lower hemisphere, poles to permeable fractures (contoured)



Zoback and Zoback, 1980

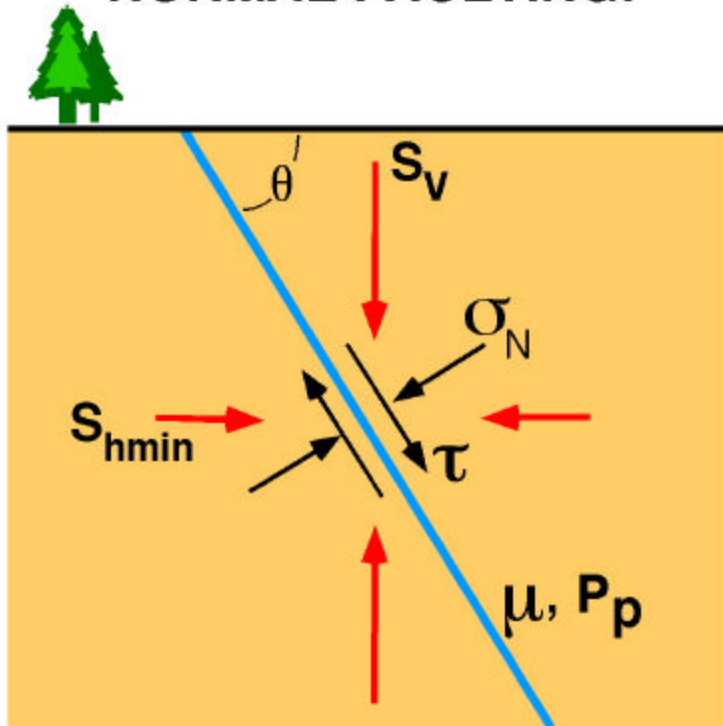






S_{Hmax} bounds assuming $C_0 = 60$ MPa (alluvium) and 80 MPa (Miocene sediments)

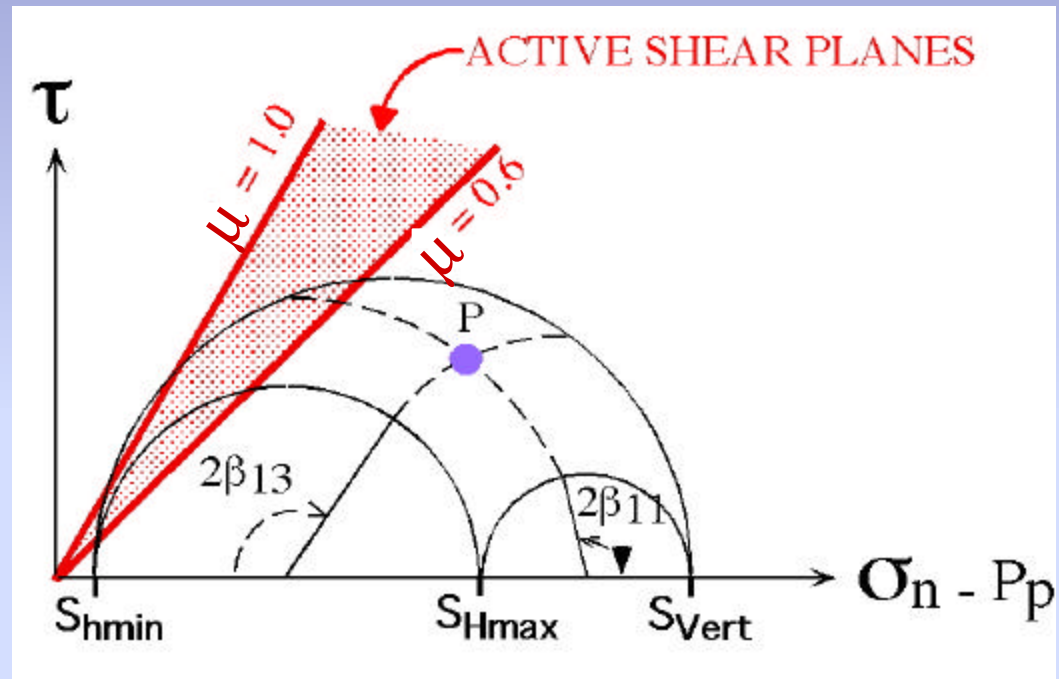
COULOMB FAILURE LAW, NORMAL FAULTING:



$$\tau_{critical} = \mu (\sigma_N - P_p)$$

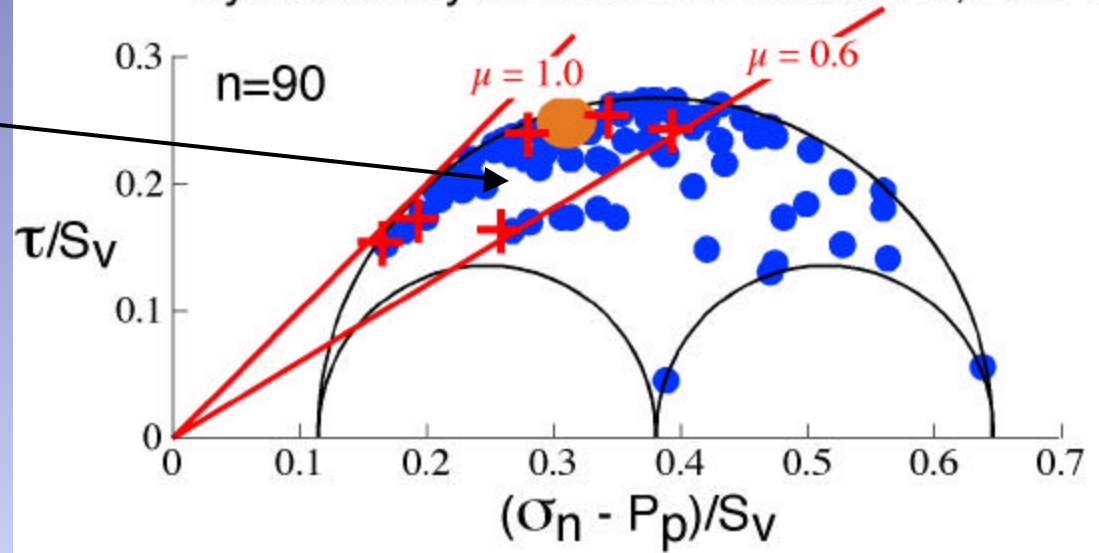
$\mu = 0.6 - 1.0$ (Byerlee's Law)

Mohr Circle, Normal Faulting

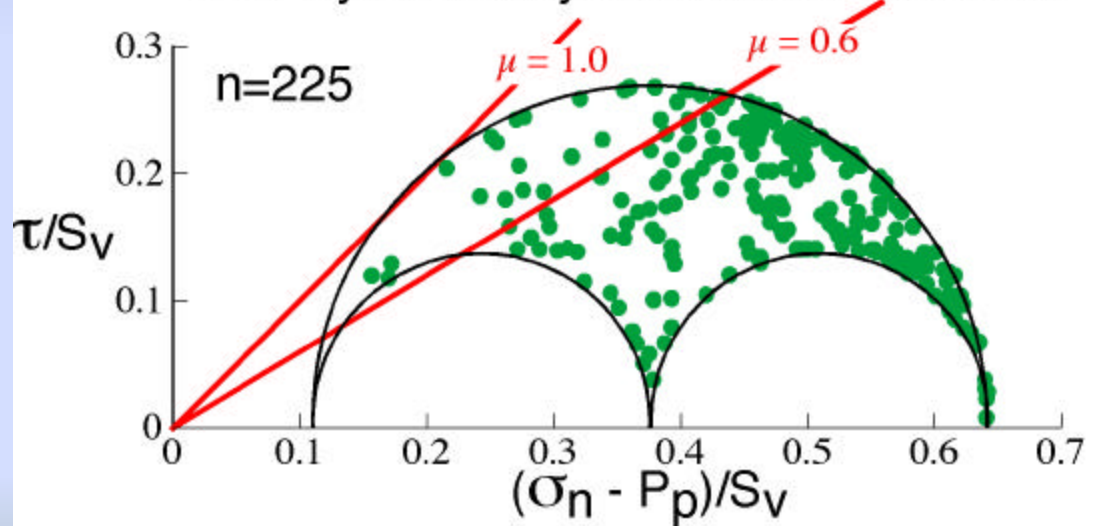


Fractures
Critically
Stressed for
Shear Failure

Hydraulically Conductive Fractures, 73B-7



Non-Hydraulically Conductive Fractures

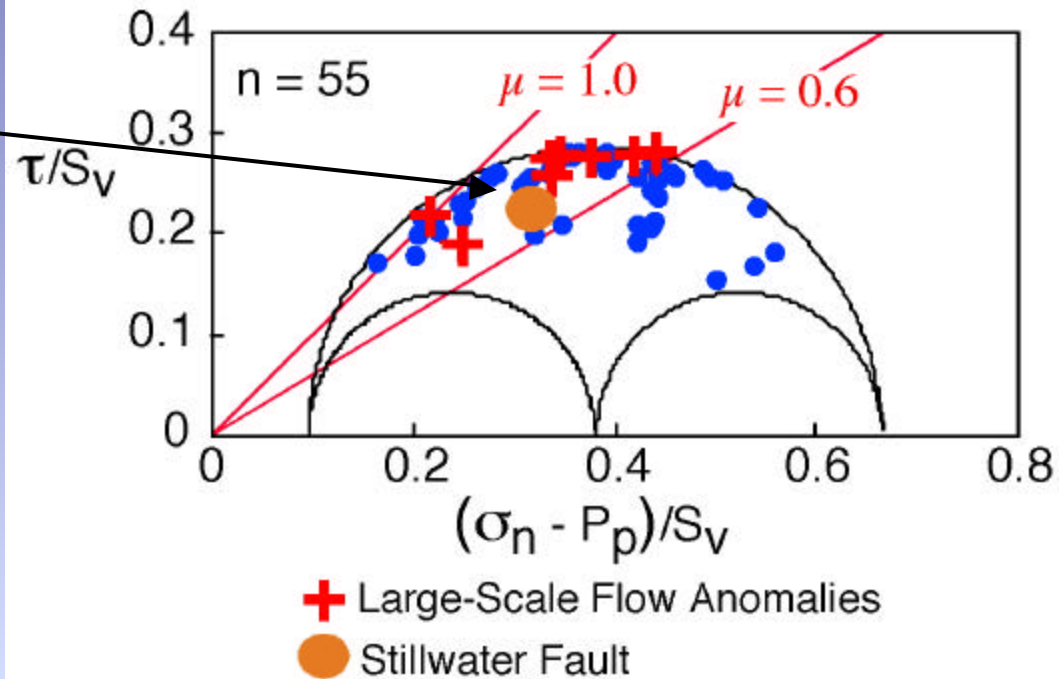


+ Large-Scale Flow Anomalies

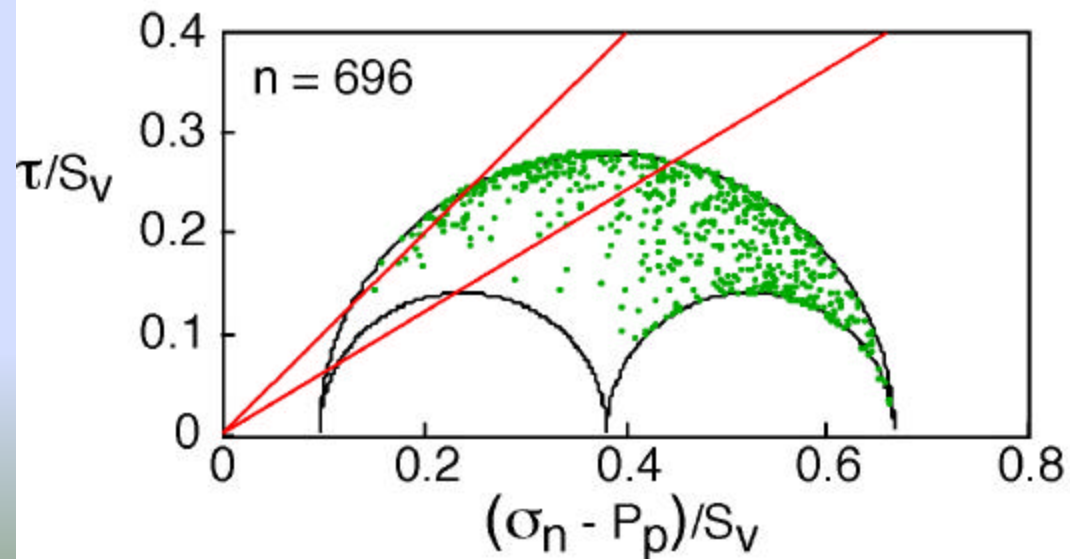
● Stillwater Fault

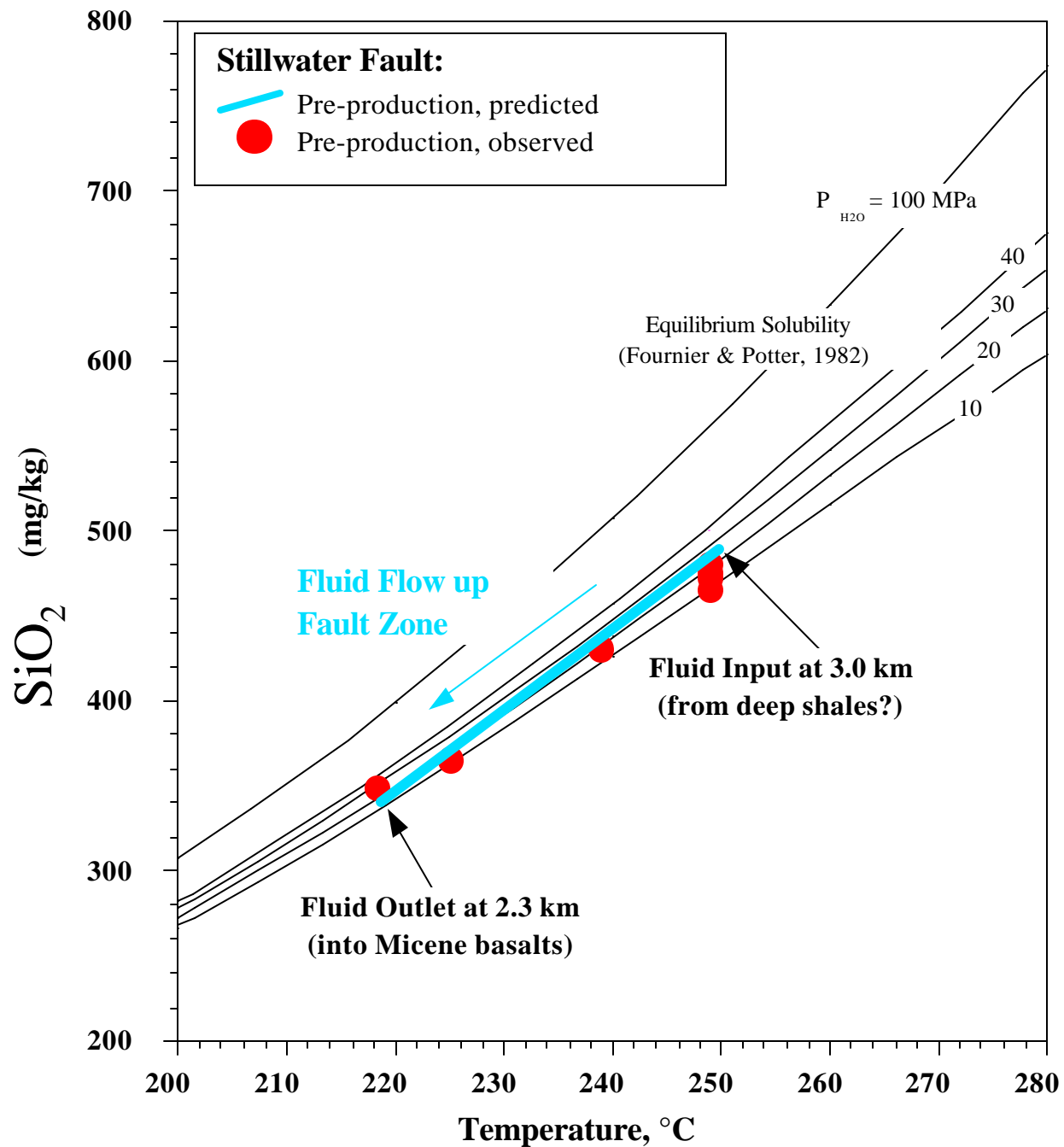
Hydraulically Conductive Fractures, 37-33

Fractures
Critically
Stressed for
Shear Failure

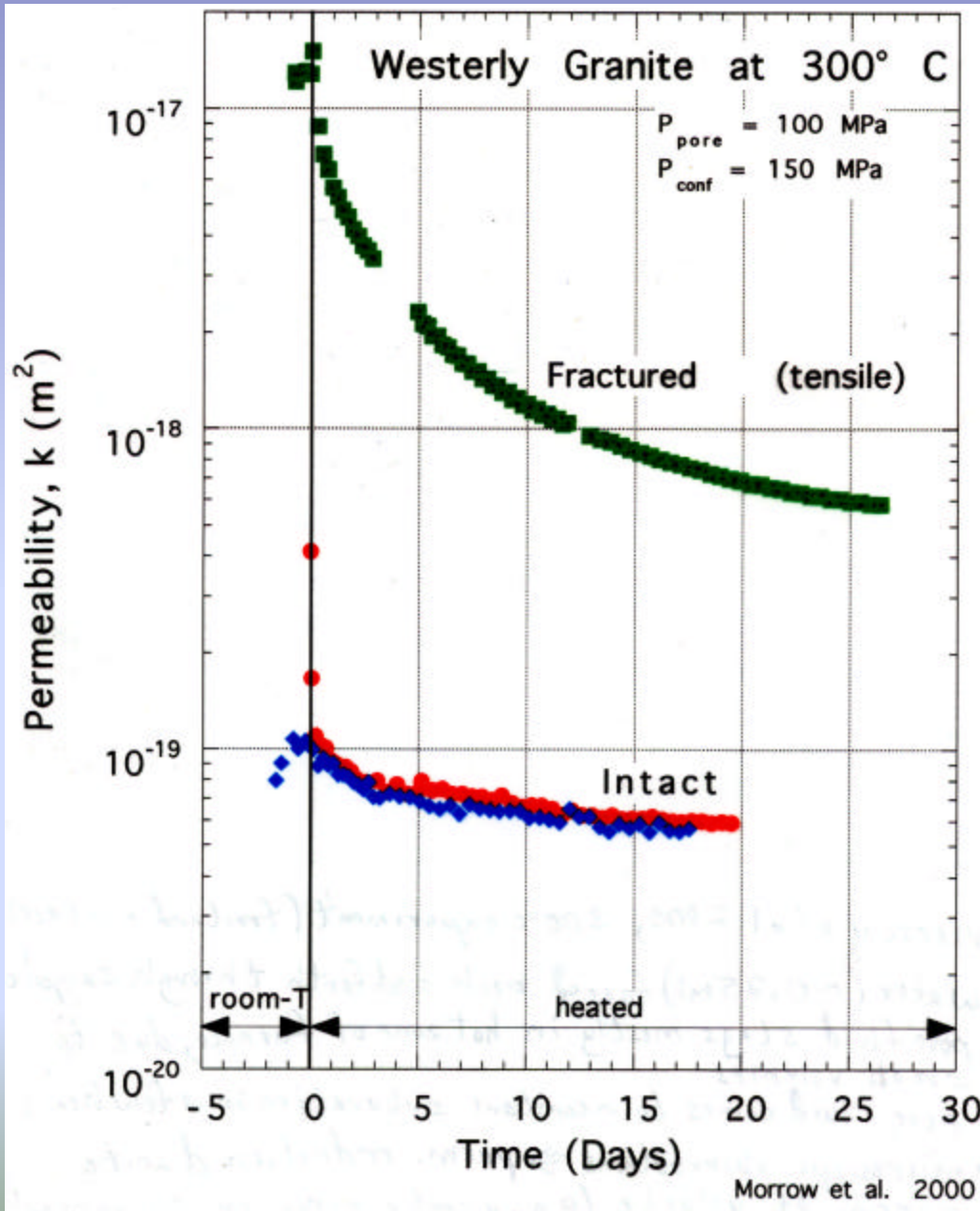


All Fractures





Laboratory Permeability Reduction at Hydrothermal Conditions



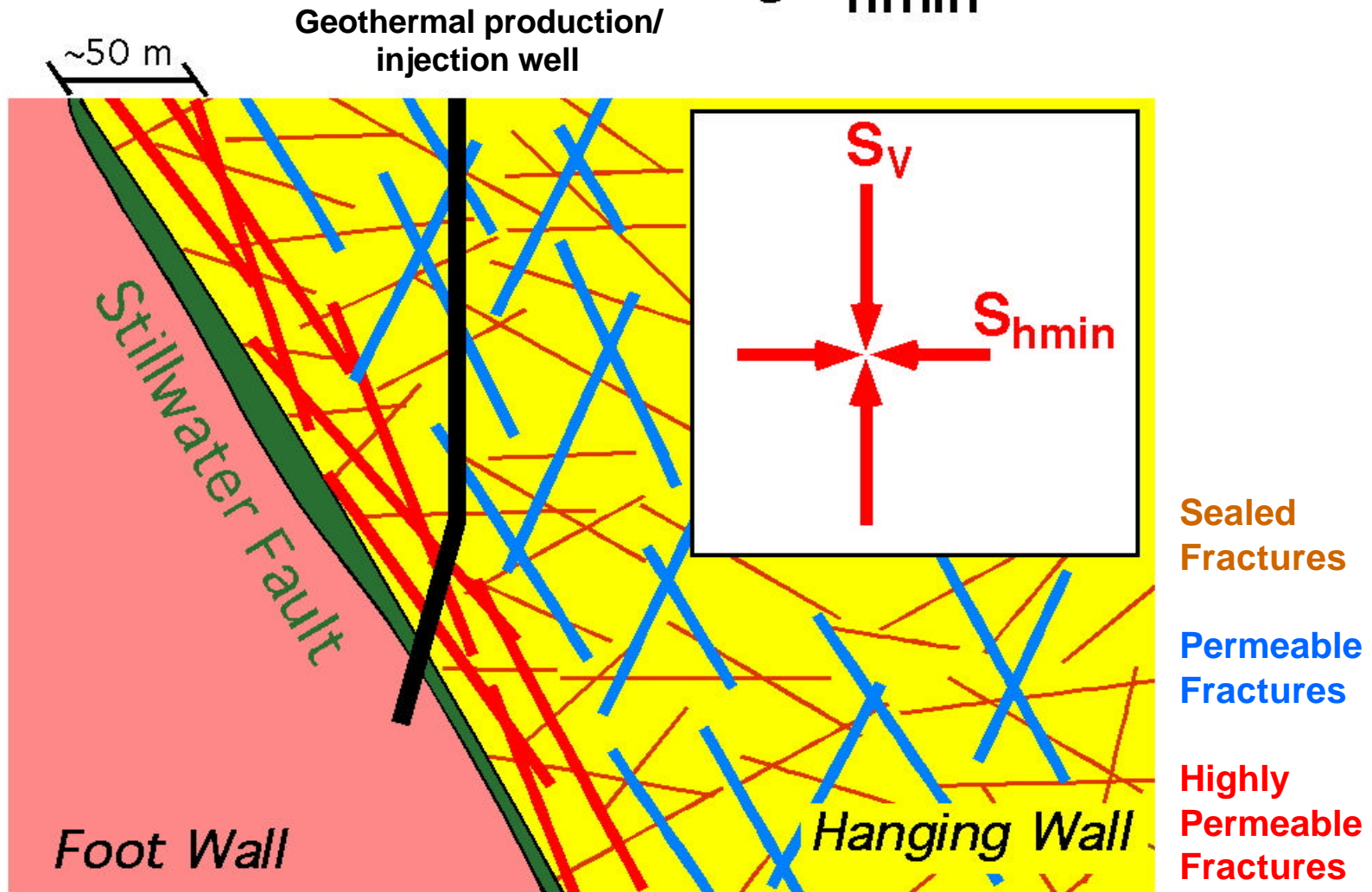
CLOSED SYSTEM

Lab results at 500 - 150° C indicate permeability reduction rates at reservoir conditions (220-250° C) of:

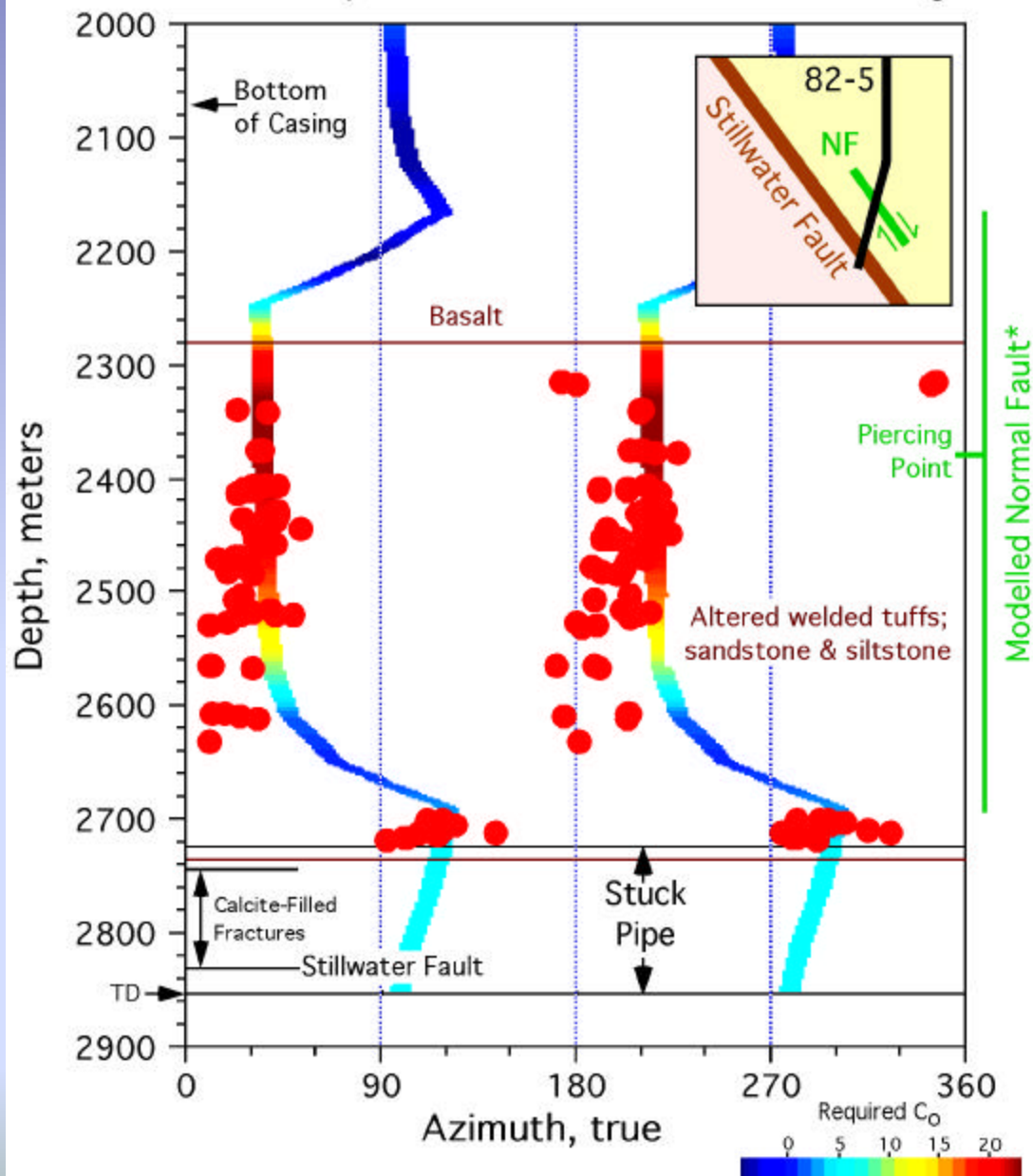
~ 5 decades/yr for fractured rock

~ 1 decade/yr for intact rock

Schematic Cross Section along S_{hmin} Direction



Dixie Valley Well 82-5: Breakout Rotation Modelling



* Fault Parameters: W=600 m, L=2000 m, Strike=N 33° E, Dip=53° SE
 Pre-Slip Stress Magnitudes (MPa): $S_{hmin}=28$, $S_{Hmax}=32$, $S_V=58$, $P_p=20$

DIXIE VALLEY GEOTHERMAL FIELD

0 2
scale, km

STILLWATER RANGE

5°

10°

73B-7,
82A-7 &
74-7

S_v
 S_{Hmax}
 S_{hmin}
66-21

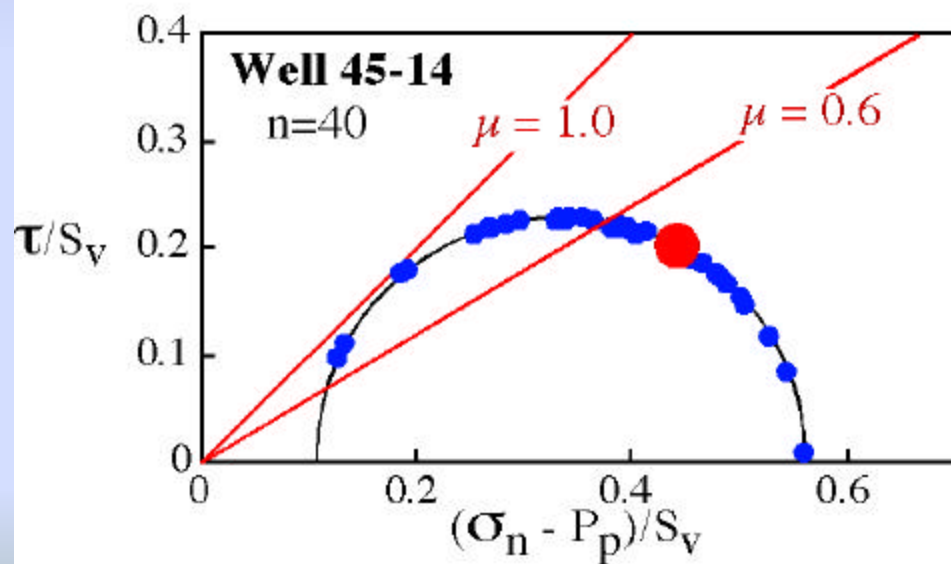
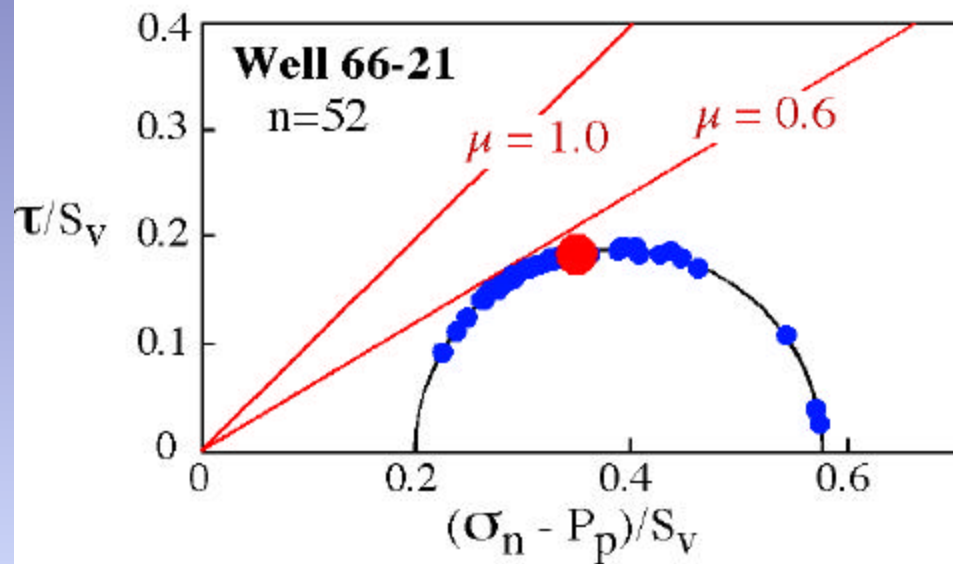
41°
45-14
DIXIE VALLEY

KEY, WELLS:

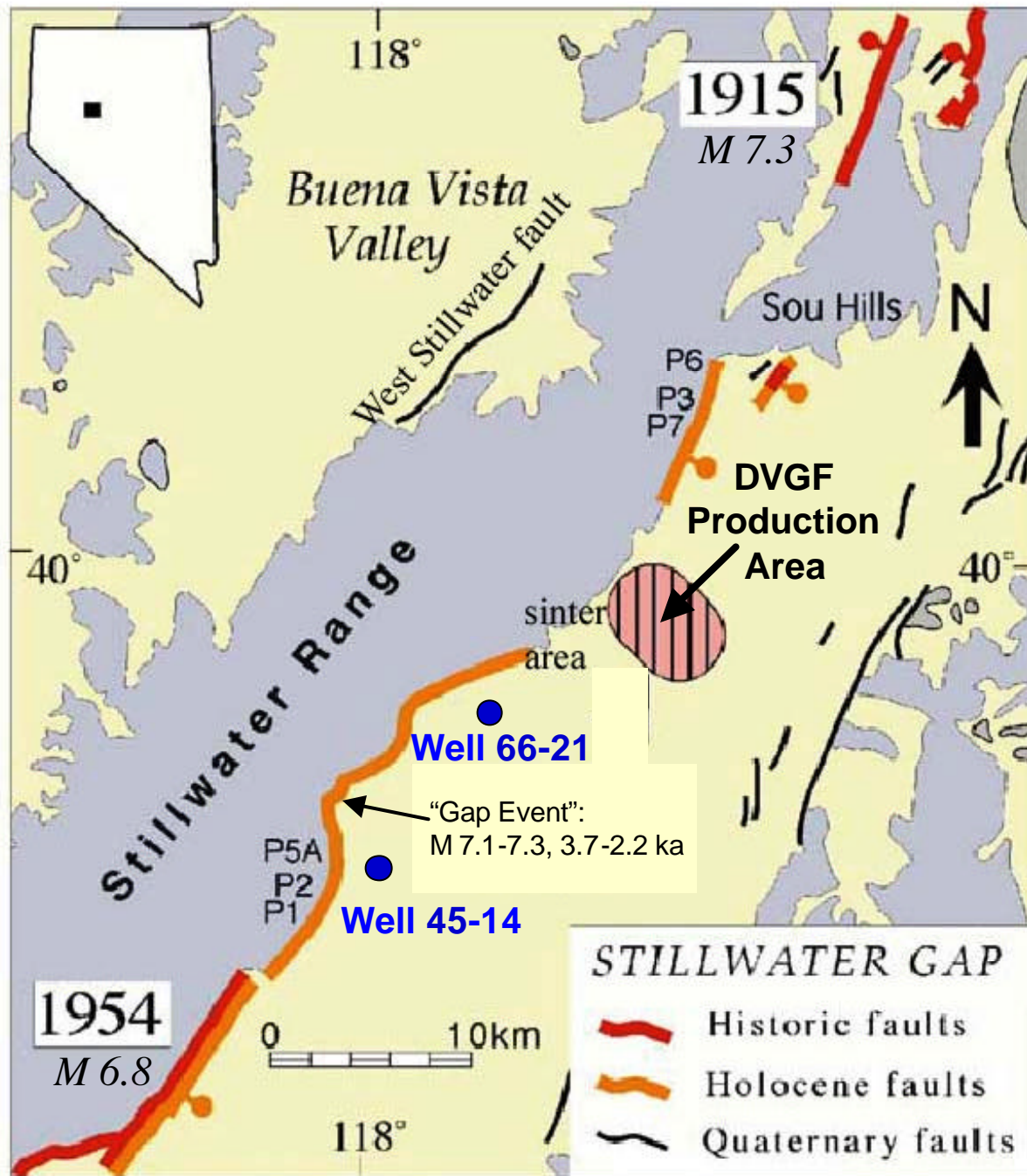
- PRODUCTION ($T \sim 1 \text{ m}^2/\text{min}$)
- OBSERVATION ($T \sim 10^{-4} \text{ m}^2/\text{min}$)

Magnitudes of S_{hmin} and S_{Hmax} shown relative to S_v (circles)

NON-PRODUCING WELLS, $S_{Hmax} \approx S_v$



- Relatively Permeable Fractures
- Stillwater Fault



Caskey and
Wesnousky, 2000

Lutz et al., 2002

CONCLUSIONS: DIXIE VALLEY GEOTHERMAL FIELD

1. The orientations of permeable fractures within the DVGF are distinct from the overall fracture population and are subparallel to the Stillwater Fault.
2. In-situ stress measurements indicate that these permeable fractures are critically stressed for frictional failure (normal faulting). Thus, dilatancy associated with intermittent fault slip appears responsible for maintaining the high fault-zone permeability.
3. Marked rotations of the horizontal principal stress directions are observed within the DVGF directly above the Stillwater Fault. These stress perturbations are best explained by small-to-moderate size earthquakes on faults subparallel to the Stillwater Fault.
4. Measurements in "dry" wells 8 and 20 km SW of the DVGF suggest that permeability is high only when individual fractures as well as the overall Stillwater Fault Zone are critically stressed for frictional failure.

